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LIGHTFASTNESS AND WEATHERFASTNESS OF OVERPRINT PATTERN OBTAINED ON POLYMER SUBSTRATES

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Original scientific paper

The flexographic technology is frequently used for printing polymer substrates and the lightfastness and weatherfastness of obtained prints is extremely important. The lightfastness and weatherfastness of prints is an ability to retain their color strength and resist fading upon exposure to sunlight. Prints with low lightfastness and weatherfastness have negative effect for sellers of various goods labeled with polymer material. It is well known that numerous polymer labels on packages are often placed on the shelves in the market where these prints are more or less exposed to sunlight and the only protection are windows. Analyses of lightfastness and weatherfastness of overprint patterns was established according to standard ISO 12040, where prints were exposed to light from Xenon lamp only and to the combination of light from Xenon lamp with added artificial rain.

Keywords: *lightfastness, polymer substrates, weatherfastness*

Svjetlostalnost i otpornost na vremenske uvjete uzoraka otisnutih na polimernim podlogama

Izvorni znanstveni članak

Fleksografska tehnologija najčešće se koristi za tiskanje na polimerne podloge, s toga svjetlostalnost te je otpornost na vremenske uvjete vrlo bitno svojstvo takvih otisaka. Svjetlostalnost i otpornost na vremenske uvjete je svojstvo otisaka kojim se izražava održavanje istog intenziteta obojenja i otpornosti prema izmjeni obojenja pod djelovanjem sunčeve svjetlosti. Otisci koji imaju malu svjetlostalnost stvaraju negativan efekt na prodavatelje polimernih etiketa. Kako je poznato, različite polimerne etikete na ambalaži smještaju se na dućanske police, gdje su ti otisci više ili manje izloženi sunčevoj svjetlosti. Jedina zaštita koja ih štiti je staklo. U ovom radu izvedene su analize svjetlostalnosti i otpornosti na vremenske uvjete prema standardu ISO 12040, gdje su otisci izlagani pod svjetlošću od samo Xenon lampe te pod kombinacijom svjetlošću Xenon lampe s dodatnom umjetnom kišom.

Ključne riječi: *otpornost na vremenske uvjete, polimerne podloge, svjetlostalnost*

1 Introduction
Uvod

The flexographic printing is the fastest growing printing technique nowadays [1]. The principal advantages of flexography are reflected in the markets where it is most often used. The advantages of flexographic printing are low cost and short circle time, precise ink transfer with minimum on-press adjustments, and ability to print one layer and laminate another layer over it in a continuous process [2].

In flexographic printing it is impossible to use one ink for different printing substrate, therefore we have several types of ink: solvent based ink, water based ink and UV and EB curable inks [3]. Both solvent based and water based inks solidify by loss of solvent and water (evaporation). Advantages of solvent based inks are good gloss, excellent adhesion, flexibility on polymer's substrates and they provide good resistance to water, acid and alkali. Main disadvantages of solvent based ink are creation of volatile organic compounds and therewith the risk for environment is increasing.

UV curing printing inks have a completely different structure than solvent based inks [4]. UV curable inks are more brilliant without content of inflammable solvent and they have strong mechanical resistance [5, 6]. These are high viscosity inks that require no drying but are photocurable. In the formulations, the solvent is replaced by monomers and photoinitiators that are crosslinked by exposure to UV radiation [2].

One of the fast growing segments in the packaging industry is flexible packaging and its flexible plastic component in particular. New plastic products and new applications for existing products are constantly coming to market. Plastic material is the second most important packaging material in Europe, after paper and board; it is also the most dynamic, with the growth based on historic trends estimated at some 4-5 % a year [7].

A wide range of polymers is used for flexible plastic packaging, depending on the required material and chemical characteristics. In the packaging and label industry among all polymers used, polyvinyl chlorides (PVC) are widely used as most versatile and suitable to deliver demanding properties. With regard to the representation of plastics, the PVC material was the third in line on the territory of North America in 2003 [8].

The oriented polypropylene (OPP) has been increasingly used as a replacement for numerous paper and PET packaging and labels. Shrink sleeve labels represent an innovative sort of labels which are unique in their properties and the process of production. The polyvinyl chloride and polyolefin are materials most frequently used for this type of labels.

This paper reports on the findings related to the lightfastness and weatherfastness of contemporary labels, which were examined by way of using PVC and OPP prints. The lightfastness and weatherfastness is a property that measures the extent to which a print will retain its original properties [9]. The ability of a label material or ink to resist after exposure to sunlight, ultra-violet light or weathering is called light resistance or lightfastness [10]. The factors are the exposure conditions, time of exposure, substrate and ink film thickness, but primarily the colorants used. The lightfastness and weatherfastness of the prints is classified according to the Blue Wool Scale [11].

This research covers visual, spectrophotometric and densitometric examination of overprint patterns obtained on PVC and OPP with solvent based and UV curable inks.

2 Experimental part
Eksperimentalni dio

Due to the mentioned fact that the flexographic print is mostly used when printing on the packaging, the testing was performed on substrates used for such packaging and labeling (oriented polypropylene and polyvinyl chloride) printed with solvent based and UV curable inks. The durability of colors and its unchanged quality play an important role especially on labels and packaging when they are exposed to the sunlight behind the window glass (in stores) or some other conditions in the environment.

This study especially focuses on changes in the durability of inks on overprint patterns. Prints were exposed to the light coming from the Xenon lamp alone and to the light from the Xenon lamp with added artificial rain in a Xenotest Alpha+ instrument (duration 72 hours). This instrument is equipped with Xenon high pressure lamp, which simulates and accelerates the natural process whereby it provides results similar to the ones obtained after being exposed to daylight. Air-cooled Xenon lamp radiates light within the spectrum from 200 to 800 nm and the temperature between 5500 and 6500 K. Pattern testing has been performed based on ISO 12040 standards. [12, 13].

2.1 Methodology
Metodologija rada

The used printing substrate, oriented polypropylene, has the thickness of 0,03 mm. The other used printing substrate, polyvinyl chloride, has the thickness of 0,042 mm. The surface energy of oriented polypropylene is 38 – 40 mN/m and of polyvinyl chloride 40 mN/m (treated with corona treatment). The tested patterns were printed with the same printing plate.

Patterns and Blue Wool Scale were partially covered with a non-transparent aluminum plate and placed inside the Xenotest instrument. The testing process was conducted based on the instructions contained in the ISO 12040 standards [12].

Two types of testing of patterns were performed: with Xenon lamp alone (CHT = 40 °C, RH = 35 %) and with Xenon lamp and 1 minute of artificial rain and 29 minutes without artificial rain (CHT = 40 °C, RH = 65 %).The period of each treatment lasted 72 hours. The visual comparison of treated patterns and Blue Wool Scale was made inside the chamber under illumination with temperature of 6500 K. The degree of lightfastness and weatherfastness was determined by establishing which degree of colour fading was noticed on the pattern in comparison to the Blue Wool Scale. The lightfastness and weatherfastness of prints is defined as the number corresponding to one of the eight Blue Wool references.

The number "1" denotes the lowest degree of lightfastness and weatherfastness and the number "8" the highest. The degrees of lightfastness and weatherfastness are classified as follows: 8 = maximum lightfastness and weatherfastness; 7 = excellent; 6 = very good; 5 = good; 4 = fairly good; 3 = moderate; 2 = poor; 1 = very poor lightfastness and weatherfastness.

The dyes used for a Blue Wool Scale are:
1 = Acid blue 104; 2 = Acid blue 109; 3 = Acid blue 83; 4 = Acid blue 121; 5 = Acid blue 47; 6 = Acid blue 23; 7 = Solubilised Vat blue 5; 8 = Solubilised Vat blue 8.

Spectrophotometric and densitometric measurements were performed using the device SpectroEye. Spectrophotometric measurements provided data on the optic properties of the pattern which were observed by way of using relative reflection curve. Relative reflection was measured with an interval of the wavelengths from 400 nm to 750 nm. The measurement conditions were: standard illumination D65 and 10 observer.

The optic properties are the material properties of substances and their changes initiate chemical changes. The observer may see the majority of objects and things in the environment due to the re-emission of a part of light which covers them coming from a primary source such as the Sun or an electric lamp. We describe that as the light which was reflected, absorbed and then transmitted [14].

The Sun or artificial source emits white light with the wavelengths between 400 nm and 700 nm and with the intensity distribution characteristic of the radiation from the body that has a temperature between 5500 K and 6500 K. When the light sprays over the material it either re-emits without changing its frequency (reflection) or it is absorbed and its energy is transformed into heat (absorption).

The densitometric measurements were used to calculate trapping characteristics of patterns. Trapping is defined as the ability (or inability) of the printed ink to accept the next layer of the printing ink [15]. Good acceptance of ink on the existing ink depends on rheology (viscosity and tackiness) of ink which is overprinted, on the ink film thickness and on the printing sequence of the inks.

3 Results and Discussion
Rezultati i rasprava

3.1 Subjective assesment of lightfastness and weatherfastness
Subjektivno ocjenjivanje svjetlostalnosti i otpornosti na vremenske uvjete

The subjective assessment of lightfastness and weatherfastness was obtained by 30 questioned persons (persons belonging to the same generation). The average values of the subjective assessment after treatment with the Xenon lamp only and after treatment with the Xenon lamp and artificial rain are presented in Fig. 1 and Fig. 2. Patterns printed with solvent based ink are presented as SBI and patterns printed with UV curable ink are presented as UVI.

Fig. 1 shows that following the treatment with the Xenon lamp, the overprint patterns printed with solvent based ink had stronger lightfastness. The highest value of the lightfastness was determined in a pattern printed with red color (Y+M) on a PVC substrate. For red (Y+M) and green (Y+C) patterns which were printed with UV curable ink on both substrates, equal or similar degrees of lightfastness were determined, while a significantly higher and same degree of lightfastness was determined with the blue (C+M) pattern.

After the treatment with the Xenon lamp and the addition of artificial rain (Fig. 2), the lightfastness and weatherfastness in overprint patterns with a solvent based ink significantly decreased. The highest lightfastness and weatherfastness was defined on a green overprint pattern

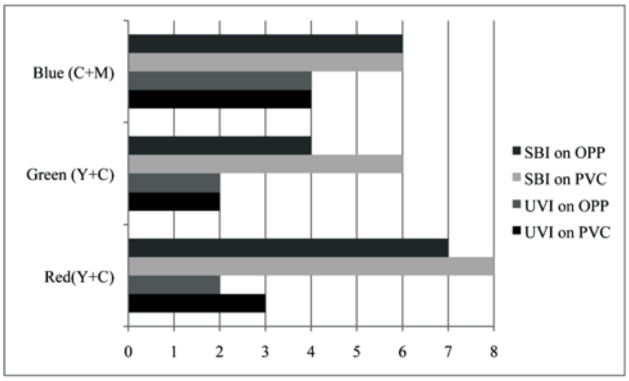

Figure 1 *Subjective assessment of lightfastness of overprint patterns after exposure to the Xenon lamp*
Slika 1. *Subjektivno ocjenjivanje svjetlostalnosti uzoraka nakon izlaganja pod Xenon lampom*

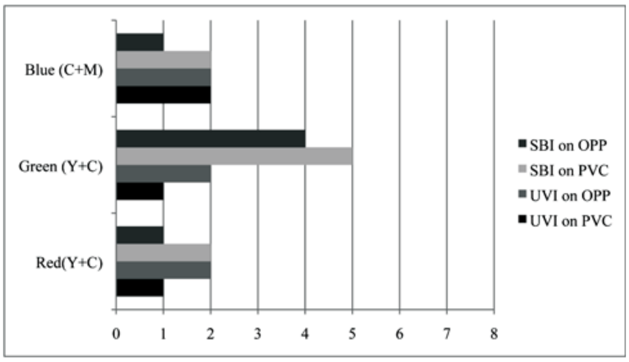

Figure 2 *Subjective assessment of lightfastness and weatherfastness of overprint patterns after exposure to the Xenon lamp with added artificial rain*
Slika 2. *Subjektivno ocjenjivanje svjetlostalnosti i otpornosti na vremenske uvjete uzoraka nakon izlaganja pod Xenon lampom s dodatkom umjetne kiše*

printed with a solvent based ink on a PVC substrate, while the least value was determined on red and green overprint patterns printed with UV curable ink on a PVC substrate. In case of patterns that were printed with UV curable ink, all patterns were determined to have the same or similarly low value of lightfastness. It is visible from the visual assessment of patterns that after being affected by the light of the Xenon lamp with added artificial rain, they have low or similar lightfastness and weatherfastness apart from the green overprint pattern (Y+C) printed on both substrates with the solvent based color.

3.2 Colour difference
Razlika u obojenju

The colorimetric values L^*, a^* and b^* were determined from measurements, and the calculation of color differences (ΔE) between the treated part of the print and the non-treated part was done. Color difference or Euclidean diference (ΔE) is the numerical value for discribing difference between two colors Equation (1) [4, 16].

$$\Delta E^* = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2} \tag{1}$$

where a^* and b^* are values which represent the hue, and the value L^* represents the lightness of the color.

Table 1 *Color difference (ΔE) between the non-treated part and the treated part of the print after exposure to the Xenon lamp*
Tablica 1. *Razlika u obojenju (ΔE) između ne-tretiranog dijela i tretiranog dijela nakon izlaganjanja pod Xenon lampom*

Xenon lamp				
ΔE	SBI on OPP	SBI on PVC	UVI on OPP	UVI on PVC
Blue (C+M)	2,13	2,82	9,65	27,17
Green (Y+C)	6,62	3,72	58,60	55,95
Red (Y+M)	3,95	2,51	4,95	4,06

Table 2 *Color difference (ΔE) between the non-treated part and the treated part of the print after exposure to the Xenon lamp with added artificial rain*
Tablica 2. *Razlika u obojenju (ΔE) između ne-tretiranog dijela i tretiranog dijela nakon izlaganja pod Xenon lampom s dodatkom umjetne kiše*

Xenon lamp + rain				
ΔE	SBI on OPP	SBI on PVC	UVI on OPP	UVI on PVC
Blue (C+M)	64,80	66,86	52,10	39,98
Green (Y+C)	9,23	6,51	72,09	67,47
Red (Y+M)	85,13	91,43	76,23	65,86

When determining the color difference (ΔE) after the treatment with Xenon lamp only (Tab. 1) greater differences were obtained on patterns printed with UV curable ink. The greatest difference was obtained on blue and green patterns. In all patterns printed with solvent based ink, minor differences were determined. In Tab. 2 differences (ΔE) between colors of patterns after the treatment with the Xenon lamp and artificial rain are significant on all patterns. Slight differences are noted on green patterns printed with solvent based ink on both substrates.

3.2 The curves of relative reflection
Krivulje relativne refleksije

The graphs show mean values of relative reflection for each overprint pattern after 20 measurements in various positions.

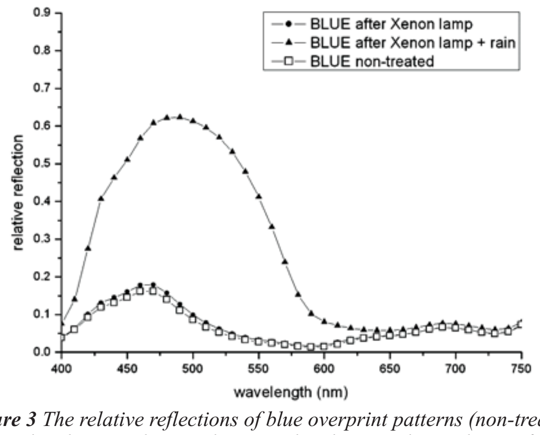

Figure 3 *The relative reflections of blue overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with solvent based ink on OPP substrate*
Slika 3. *Relativne refleksije plavih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s bojilom na bazi otapala na OPP podlozi*

After the blue overprint pattern had been exposed to the Xenon lamp only, no change occurred in the relative reflection, while the exposure to the Xenon lamp with an addition of artificial rain resulted in significant changes in the blue and green wavelength intervals (Fig. 3).

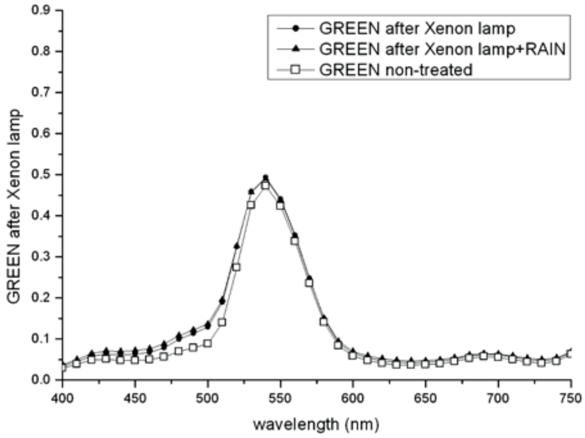

Figure 4 *The relative reflections of green overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with solvent based ink on OPP substrate*
Slika 4. *Relativne refleksije zelenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s bojilom na bazi otapala na OPP podlozi*

Fig. 4 shows that the relative reflection curves of the pattern treated with Xenon lamp only and Xenon lamp plus artificial rain are similar to the relative reflection curve of a non-treated pattern. A low value of a reflection increase is noted in the lower wavelength of both treated patterns.

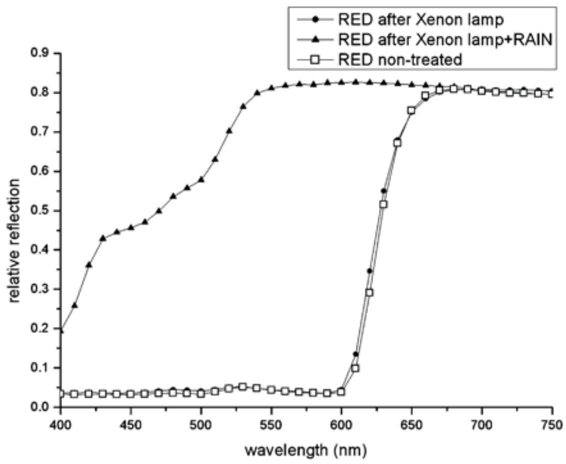

Figure 5 *The relative reflections of red overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with solvent based ink on OPP substrate*
Slika 5. *Relativne refleksije crvenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s bojilom na bazi otapala na OPP podlozi*

After the treatment with the Xenon lamp only, the red pattern had the same relative reflection as the non-treated pattern (Fig. 5). The curve of the relative reflection of a red pattern after it had been treated with the Xenon lamp and the artificial rain has higher increase values in the green part of the spectra while the lower increase value may be detected in the blue interval.

The blue pattern printed with the solvent based ink (Fig. 6) on the polyvinyl chloride substrate and treated only with the Xenon lamp, did not experience changes in its relative reflection curve. The change is visible only in the low decrease of reflection. After the treatment with the Xenon lamp and artificial rain the curve of the relative reflection became higher in the blue and green interval.

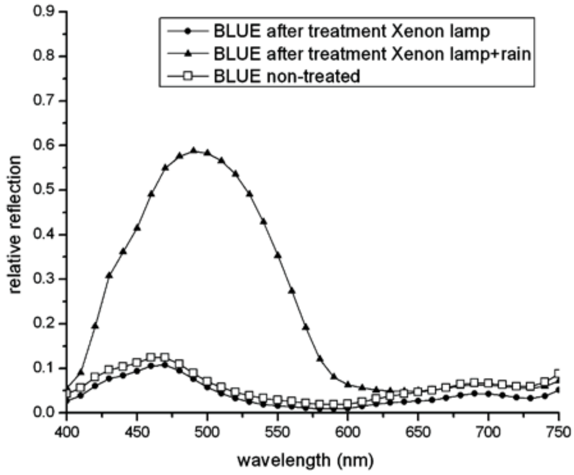

Figure 6 *The relative reflections of blue overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with solvent based ink on PVC substrate*
Slika 6. *Relativne refleksije plavih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s bojilom na bazi otapala na PVC podlozi*

After the application of both treatments, no significant change occurred in relation to the curves of the relative reflection of the green pattern (Fig. 7). A slight decrease in the curve of the relative reflection after the application of both treatments is visible in the blue and red area.

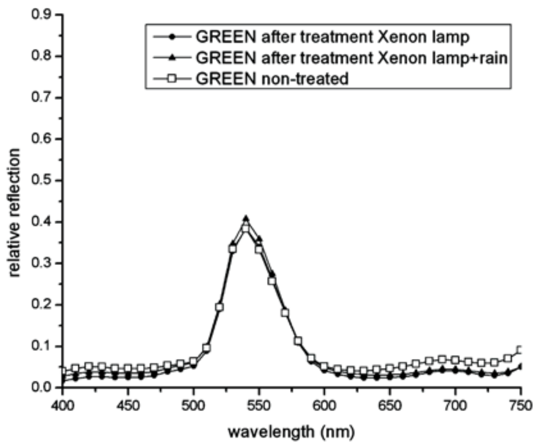

Figure 7 *The relative reflections of green overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with solvent based ink on PVC substrate*
Slika 7. *Relativne refleksije zelenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s bojilom na bazi otapala na PVC podlozi*

It is visible in Fig. 8 that there is a slight decrease in the curve of relative reflection in the red area after the red pattern has been treated with the Xenon lamp only. The relative reflection curve of the red pattern after the treatment with the Xenon lamp and artificial rain was significantly increased in the green area and only slightly in the blue area.

Fig. 9 shows the overlapping of curves of the relative reflection of the non-treated pattern and the pattern that has been treated with the Xenon lamp only. After the treatment with the Xenon lamp and the artificial rain, the range of the blue pattern increased in the blue and green part of the spectra.

After the application of both treatments, changes occurred in the relative reflection curves with the green

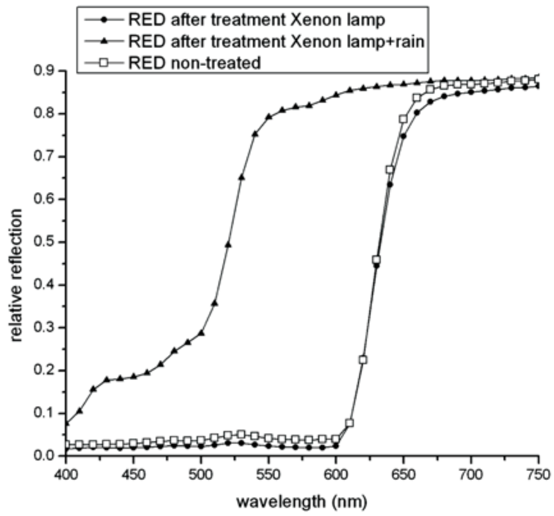

Figure 8 *The relative reflections of red overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with solvent based ink on PVC substrate*
Slika 8. *Relativne refleksije crvenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s bojilom na bazi otapala na PVC podlozi*

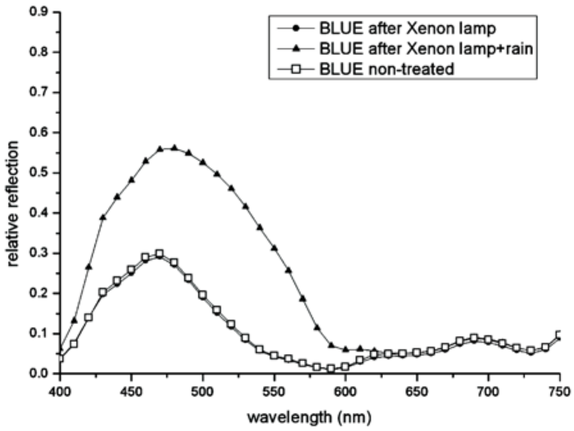

Figure 9 *The relative reflections of blue overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with UV curable ink on OPP substrate*
Slika 9. *Relativne refleksije plavih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s UV bojilom na OPP podlozi*

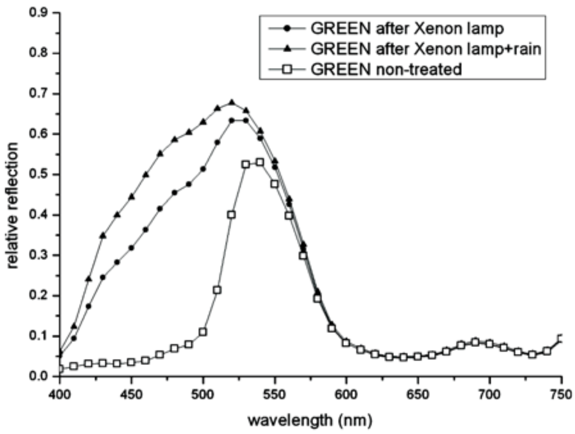

Figure 10 *The relative reflections of green overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with UV curable ink on OPP substrate*
Slika 10. *Relativne refleksije zelenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s UV bojilom na OPP podlozi*

pattern (Fig. 10). After the treatment with the Xenon lamp only, a change of the curve occurred in the blue part of the spectrum. Likewise, after the treatment with the Xenon lamp and artificial rain, a significant increase of the reflection took place in the blue part which is slightly higher when compared to the curve of the pattern after it had been treated with the Xenon lamp only.

The red pattern, after the treatment with the Xenon lamp only (Fig. 11), had an increase in the reflection in the area of low wavelengths. However, after the treatment with the Xenon lamp and artificial rain differences in the reflection are greater especially in the green interval.

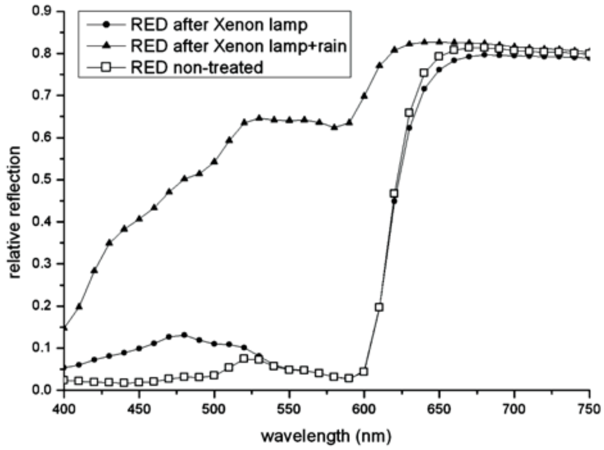

Figure 11 *The relative reflections of red overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with UV curable ink on OPP substrate*
Slika 11. *Relativne refleksije crvenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s UV bojilom na OPP podlozi*

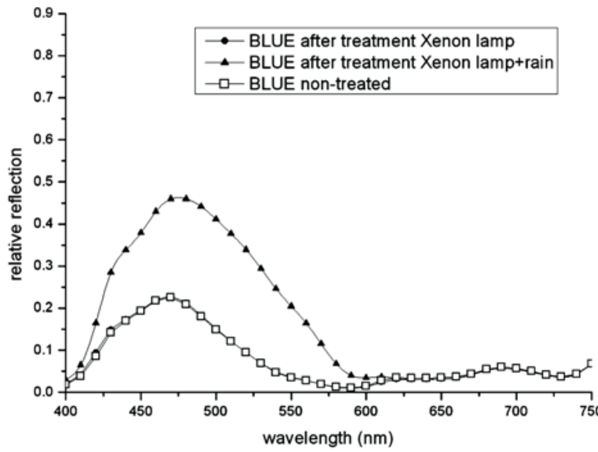

Figure 12 *The relative reflections of blue overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with UV curable ink on PVC substrate*
Slika 12. *Relativne refleksije plavih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s UV bojilom na PVC podlozi*

Fig. 12 shows that there are no differences between the reflection of a non-treated blue pattern and a blue pattern that has been treated with the Xenon lamp only. The increase in the green and blue area occurred after the treatment with the Xenon lamp and artificial rain.

After the application of treatment with the Xenon lamp only and the Xenon lamp with the artificial rain, the reflection increase occurred in the blue area. It is higher with the pattern that was treated with the Xenon lamp and artificial rain as compared to the reflection pattern after it

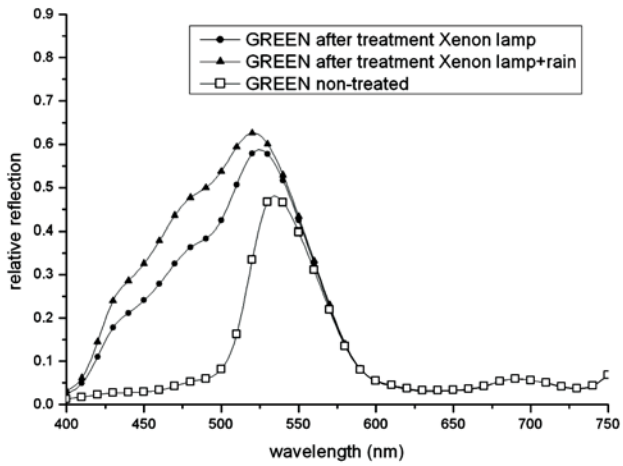

Figure 13 *The relative reflections of green overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with UV curable ink on PVC substrate*
Slika 13. *Relativne refleksije zelenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s UV bojilom na PVC podlozi*

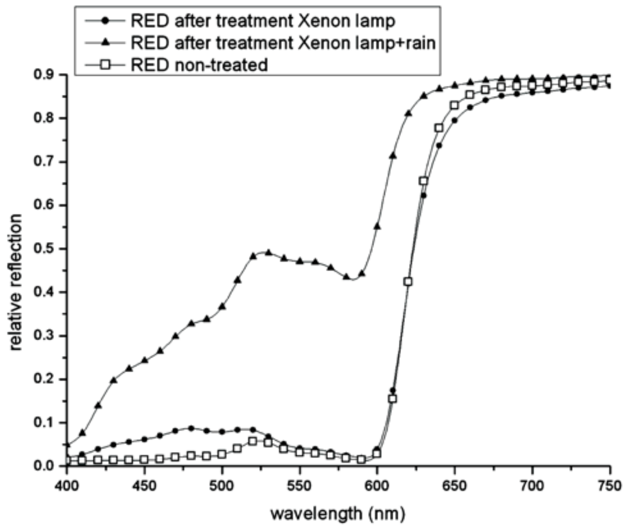

Figure 14 *The relative reflections of red overprint patterns (non-treated; treated with Xenon lamp only; treated with Xenon lamp plus artificial rain) printed with UV curable ink on PVC substrate*
Slika 14. *Relativne refleksije crvenih uzoraka (ne-tretiranog; tretiranog sa samo Xenon lampom; tretiranog sa Xenon lampom i umjetnom kišom) koji su otisnuti s UV bojilom na PVC podlozi*

was treated with the Xenon lamp only (Fig. 13).

With the red pattern (Fig. 14), after it was treated with the Xenon lamp only, the relative reflection curve slightly changed, that is, it increased in the area of low wavelengths and decreased in the area of longer wavelength interval. After the treatment with the Xenon lamp and artificial rain, the pattern curve significantly changed, mostly in the green area and less in the blue area (increase) and in the red area the curve moved in the direction of green area.

3.3 The standard deviation
Standardna devijacija

The standard measuring deviation has been calculated from the obtained mean relative reflection values, from which we can obtain information on the quality of the print.

The standard deviation is a statistical notion, which represents a measure of how individual readings in a group are spread out.

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1}} \tag{2}$$

where x is a variable from which are calculated ($x=i....n$), n total amount of variables and μ the mean value of distribution [17].

The range of standard deviation on patterns that have not been treated and have been treated with the Xenon lamp only and with the Xenon lamp and artificial rain, is presented in Figs 12, 13 and 14.

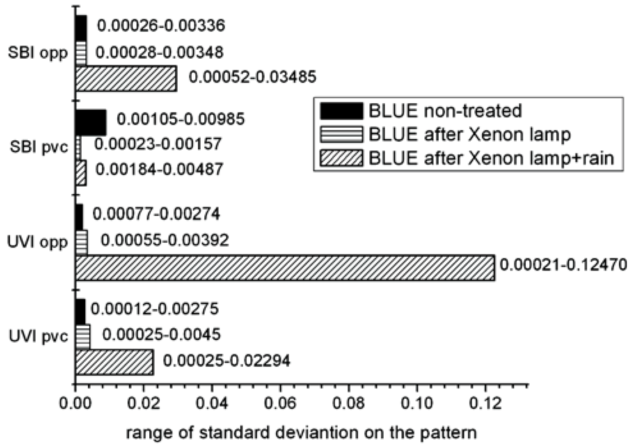

Figure 15 *The range of standard deviation on the blue overprint pattern*
Slika 15. *Raspon standardnih devijacija kod plavog uzorka*

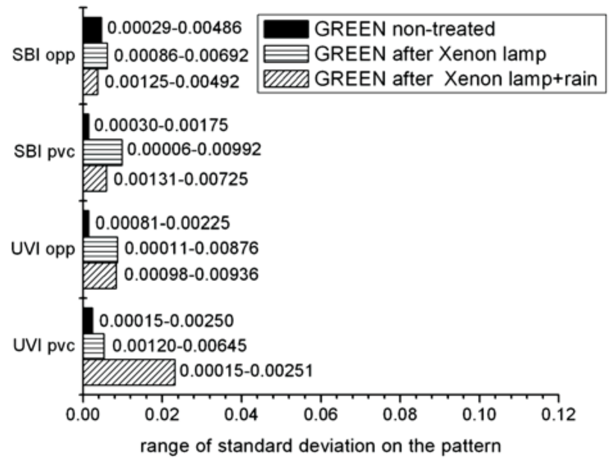

Figure 16 *The range of standard deviation on the green overprint pattern*
Slika 16. *Raspon standardnih devijacija kod zelenog uzorka*

The highest range of standard deviation in the spectrometric measures of the blue pattern (Fig. 15) is on the pattern printed in UV curable ink on the OPP substrate after the treatment with the Xenon lamp and the artificial rain. Non-treated patterns and patterns treated with the Xenon lamp only have the same or similar range of deviation with all patterns except for patterns printed with solvent based ink on the PVC substrate, whereby the treated pattern has a higher range of standard deviation than the treated pattern. After the applications of treatment with the Xenon lamp and the artificial rain all blue patterns have higher range of standard deviation in relation to non-treated patterns and patterns treated only with the Xenon lamp.

The green patterns, after having been treated in both ways (with the Xenon lamp only and with the Xenon lamp and artificial rain) have similar values in the range of their

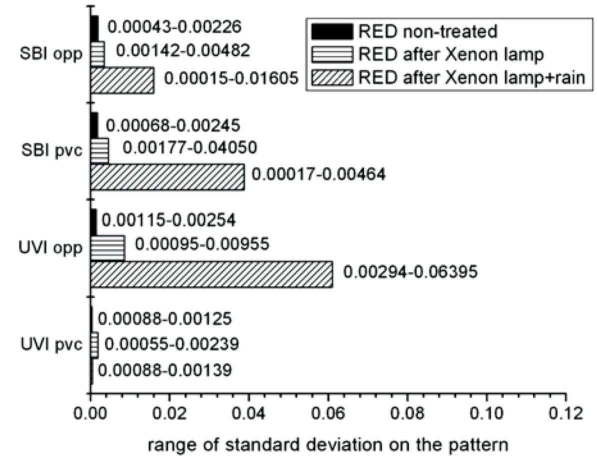

Figure 17 *The range of standard deviation on the red overprint pattern*
Slika 17. *Raspon standardnih devijacija kod crvenog uzorka*

standard deviation, except with the pattern printed with the UV color on the PVC substrate, where one has a higher range of the standard measuring deviation (Fig. 16). Non-treated patterns have lower range of the standard measuring deviation in relation to the treated patterns.

It is visible in Fig. 17 that patterns that were printed with the UV ink on the PVC substrate have the lowest standard measuring deviation ranges in relation to a non-treated pattern and in relation to a treated pattern. With other patterns, relative to the non-treated patterns, the increase in the standard measuring deviation range is cascaded and it has the highest value with patterns that have been treated with the Xenon lamp and the artificial rain.

3.4 Trapping characteristics
Karakteristike primanja bojila na bojilo

The patterns have also undergone a densitometric testing. The values obtained through densitometric testing were used for calculating trapping characteristics. The formula (3) is used for assessing the quality of trapping characteristics for two inks [15].

$$F_{\mathrm{tr}} = \frac{1-10^{-D_{F1+F2}}}{1-10^{-(D_{F1}+D_{F2})}} \qquad (3)$$

in which F_{tr} represents the complete coating of the last ink. D_{F1} represents the density of coloration of the solid first printed ink area measured with a complementary filter. D_{F2} represents the density of coloration of the solid second printed ink area measured with a complementary filter and D_{F1+F2} the density of coloration of the solid ink area for both inks measured with the complementary filter.

Trapping characteristics of the non-treated patterns, treated patterns after exposure to the Xenon lamp and treated patterns after exposure to the Xenon lamp with added artificial rain are shown in Tables 3, 4 and 5.

It is visible from Tab. 3 that trapping characteristics are very good and the values of patterns are similar. The green pattern printed in solvent based ink is the only one whose trapping value differs significantly - 101,20.

Trapping characteristics of the treated patterns after exposure to the Xenon lamp only have remained extremely good, except with the green pattern printed with the UV curable ink on OPP and PVC substrate (Tab. 4).

Table 3 *Trapping characteristics of the non-treated patterns*
Tablica 3. *Karakteristike primanja bojila na bojilo kod ne-tretiranog uzorka*

F_{tr}	SBI on OPP	SBI on PVC	UVI on OPP	UVI on PVC
Blue	98,86	99,62	98,27	96,64
Green	101,20	99,68	98,33	99,01
Red	98,63	99,39	99,15	99,50

Table 4 *Trapping characteristics of the treated patterns after exposure to the Xenon lamp*
Tablica 4. *Karakteristike primanja bojila na bojilo kod tretiranog uzorka sa Xenon lampom*

F_{tr}	SBI on OPP	SBI on PVC	UVI on OPP	UVI on PVC
Blue	96,21	98,57	98,06	96,23
Green	99,53	98,88	60,17	58,79
Red	98,11	99,38	84,31	98,54

Table 5 *Trapping characteristics of the treated patterns after exposure to the Xenon lamp with added artificial rain*
Tablica 5. *Karakteristike primanja bojila na bojilo kod tretiranog uzorka sa Xenon lampom uz dodatak umjetne kiše*

F_{tr}	SBI on OPP	SBI on PVC	UVI on OPP	UVI on PVC
Blue	20,73	16,93	52,11	73,89
Green	98,04	97,91	34,22	36,96
Red	3,20	10,32	7,08	63,02

Tab. 5 shows significant difference in the trapping values. Significantly low values were obtained with the red pattern printed on OPP substrate while the still satisfactory values were obtained with the green pattern printed in solvent based ink.

4 Conclusion
Zaključak

Patterns printed with solvent based inks show higher lightfastness after Xenon lamp treatment. The red and green overprint patterns obtained with UV inks have the lowest lightfastness after Xenon lamp treatment. After combined Xenon lamp and artificial rain the ligthfastness of patterns printed with solvent based inks is decreased. The green pattern (Y+C) printed in solvent based ink in the most sustainable pattern after both treatments.

It is visible from the value in the coloration differences that the green pattern printed with the UV curable ink has significant differences in the coloration in relation to both substrates after the treatment with the Xenon lamp only. All overprint patterns differ significantly with regard to color change after exposure to the Xenon lamp and artificial rain, while the green pattern printed in solvent based ink suffers less color change, which is still inacceptable.

By way of observing relative reflection curves after the application of treatment with the Xenon lamp only, it was noted that the reflection of patterns printed in solvent based ink was not significantly changed. It was visible also with regard to the green pattern printed in solvent based ink that the reflections prior and after the application of both treatments were not changed. The values of the trapping confirmed that as well.

The red pattern printed in solvent based ink on both substrates, after the treatment with the Xenon lamp and artificial rain, evidently changed the reflection curve. We could therefore notice that the print had a yellowish coloration, that is, that the magenta ink almost completely disappeared, which is confirmed with the values of the trapping. With the blue pattern printed in solvent based ink, an intensive reflection occurred in the blue and green areas, which shows that the pattern got cyan coloration, and depending on the curve intensity, the coloration is stronger or weaker.

Patterns that were printed in UV ink behave similarly, except for the red pattern on both substrates, which, after treatment with the Xenon lamp only, had an increased reflection in the area of low wavelengths, that is, took over the coloration of magenta. The green pattern printed in UV ink had changes in the reflection even after it had been treated with the Xenon lamp only and after the treatment with the Xenon lamp and artificial rain. The changes occurred in the green and blue area that indicates that the pattern had cyan coloration of a lower intensity in relation to the green pattern printed in solvent based ink.

From the range of standard deviations it is visible that the fading of coloration is not the same throughout the pattern surface. The largest deviation is visible with the blue and red patterns printed in UV ink on OPP substrate and with the blue and red patterns printed on the OPP substrate and the green pattern printed on the PVC substrate, which is the effect of the yellow ink influence.

The lightfastness and weatherfastness of all researched pattern decreases after the application of treatment with the Xenon lamp and artificial rain, wherefrom we can conclude that the sustainability of the pattern color should be defined by way of exposing patterns to the Xenon lamp and artificial rain in order to simulate the actual environment, which the patterns, that is, graphic products, would be placed and exposed in.

The research presented in this paper has proven that the sustainability of colors varies depending on the various external influences, and has revealed a new field in which further scientific research may determine different correlations among parameters affecting the ink quality, that is, the print, and subsequently also the quality of a final graphic product.

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